Electronic Devices and Circuits Lab Experiment-3

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AIM

To understand the following characteristics of the p-n Junction Diode through simulations using ABACUS tool on nanohub.org:

1. Electron and hole concentrations on the p-side and n-side.
2. The structure of energy bands at the junction.
3. Electric Field in the device.
4. Current-Voltage characteristics of the diode.

THEORY

p-n junction diodes are simple semiconductor devices that permit the flow of current in only one direction. This is done by using strategically placed atomic impurities to create an electric field within the semiconducting material. These diodes can be fabricated in various ways, such as thermal oxidation, diffusion, ion implantation, etc. Here, we consider only the junction with an abrupt change from p-type to n-type semiconductor.

When we do not apply any voltage across the p-n diode (i.e., at equilibrium), free electrons will diffuse through the junction to the p-side, and holes will diffuse through the junction to the n-side, and they combine. Thus, the acceptor atoms in the p-side near the junction edge and donor atoms in the n-side near the junction edge become negative and positive ions. The existence of opposite ions on either side of the junction edge creates an electric field (or diffusion potential), which opposes further diffusion of free electrons from the n-type side and holes from the p-type side of the p-n junction diode. We call this region across the junction where the ions exist as the depletion region. Hence, the net current is zero due to drift current (diffusion potential) and diffusion current nullifying each other.

If we apply forward bias voltage to the **p-n junction diode**, i.e., if the positive side of the battery is connected to the p-side, then the depletion regions width decreases, and carriers (holes and free electrons) flow across the junction, i.e., net current isn't zero.
And in case we apply a reverse bias voltage to the diode, the depletion width increases, and no charge can flow across the junction.

PROCEDURE

To plot the graphs, we set some parameters in the ABACUS tool, which are as follows:

1. N_A = 10^18 cm^-3 and N_D = 10^17 cm^-3
2. Length of p-type and n-type semiconductor = 6µm
3. Number of nodes of p-type and n-type semiconductor = 120

The rest are taken as the ones given by default. We set the applied bias voltage using the slider below the plot in ABACUS. Then, we download the datasheet and use it to plot it in Octave.

RESULTS AND UNDERSTANDING

Electron and Hole Concentration

The p-n junction is positioned 6µm from either side. Away from the junction, the electron and hole concentration is equal to $N_D = 10^{17} cm^{-3}$ and $N_A = 10^{18} cm^{-3}$respectively. However, the concentration of charge carriers at the junction will depend on the applied bias.
At equilibrium (applied bias voltage = 0V), diffusion potential restricts the movement of charge carriers, which leads to a sharp change in the concentration of charge carriers across the junction. If we apply a positive bias voltage, the potential barrier across the junction is reduced (as the applied voltage is opposite to diffusion potential), and the charge carriers can now move more freely in the depletion region. This indicated a gradual change in concentrations of charge carriers across the junction.

Structure of Energy Bands

The conduction band of p-type semiconductor is higher than the conduction level of n-type semiconductor, which acts as an energy barrier for electrons. When a positive bias is applied, diffusion potential is reduced, thereby lowering the conduction and valence band of p-type semiconductor. Hence, electrons can now cross the barrier to jump across the junction.

The Fermi Level depends on the applied bias in the following way:

- At the equilibrium state of the diode, there is no flow of electrons. Therefore, the Fermi Level must be constant throughout the length of the semiconductor.
- When the positive bias is applied, Fermi Level is split into Quasi Fermi Levels. As stated previously, the conduction and valence band of the p-type semiconductor is lowered, along with the quasi-Fermi level of the p-type semiconductor.

Electric field in the Device

The electric field is always zero at distances away from the junction, and at the p-n junction, there is a dip in the plot around 6µm. This is due to the electric field (from n-side to p-side) generated by ions on either side of the junction. And as seen previously, the application of positive bias leads to the reduction of this electrical field. Hence, the dip would become smaller when we apply bias voltage.

Current-Voltage Characteristics

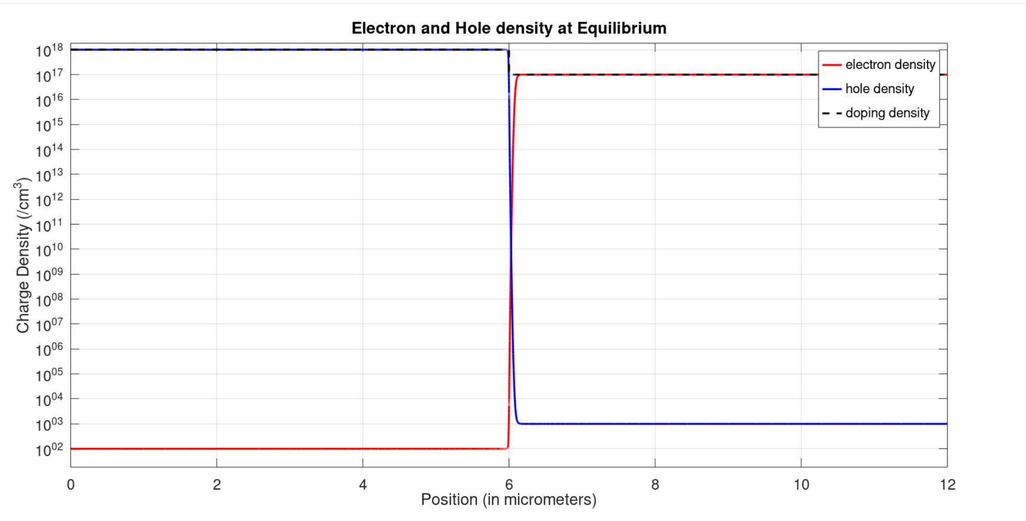
The current-voltage characteristics of a p-n junction diode is non-linear. The phenomenon occurs as the applied voltage initially reduces the potential barrier, and the current can only flow when the applied voltage overcomes the potential barrier. Hence, the current starts flowing after a particular voltage (cut-off voltage), depending on the height of the potential barrier.

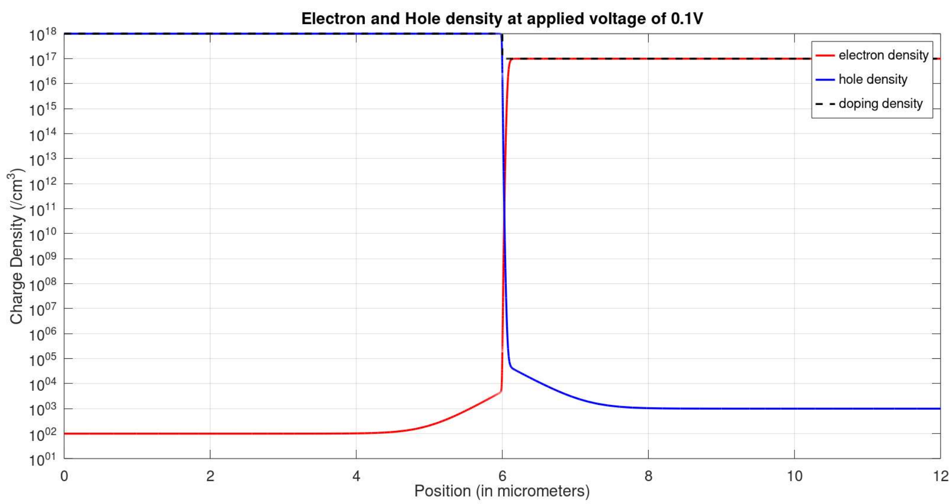
CONCLUSIONS

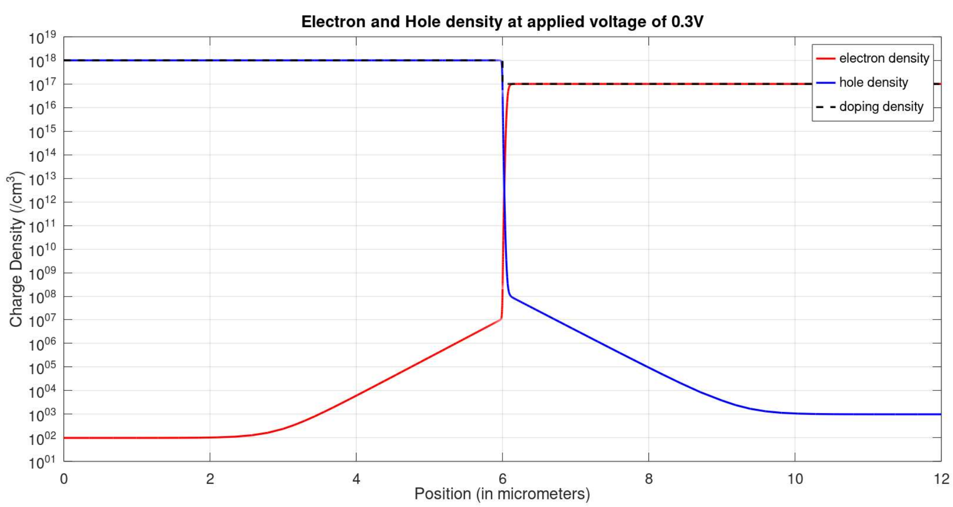
- The electron and hole concentration gradually increases near the junction as we increase the positive bias applied.
- When a positive bias (not equal to 0V) is applied, the Fermi Level is split into quasi-Fermi Levels. While at equilibrium, the Fermi levels of n-type and p-type semiconductors overlap.
- The electric field across the p-n junction decreases with applied bias.
- The current in a positive biased diode starts increasing with voltage after a certain cut-off voltage.

PLOTS

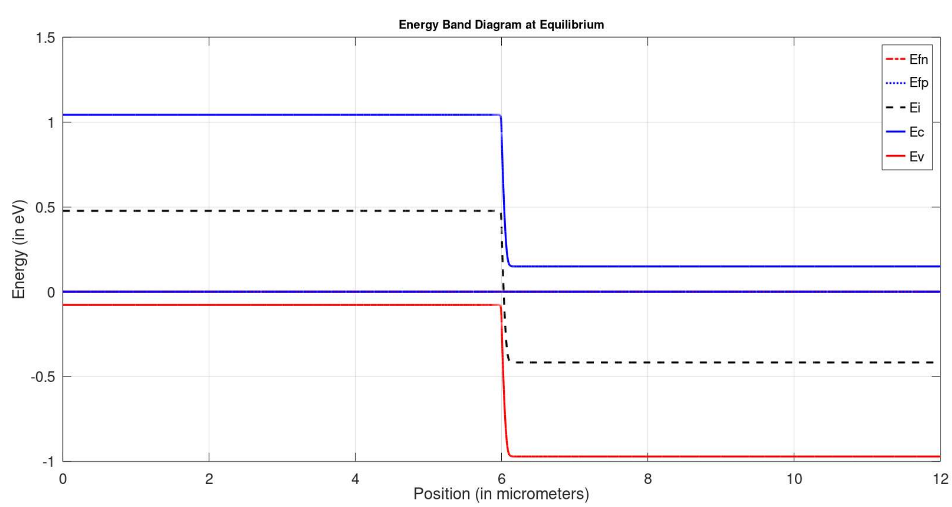
Electron Hole Concentrations

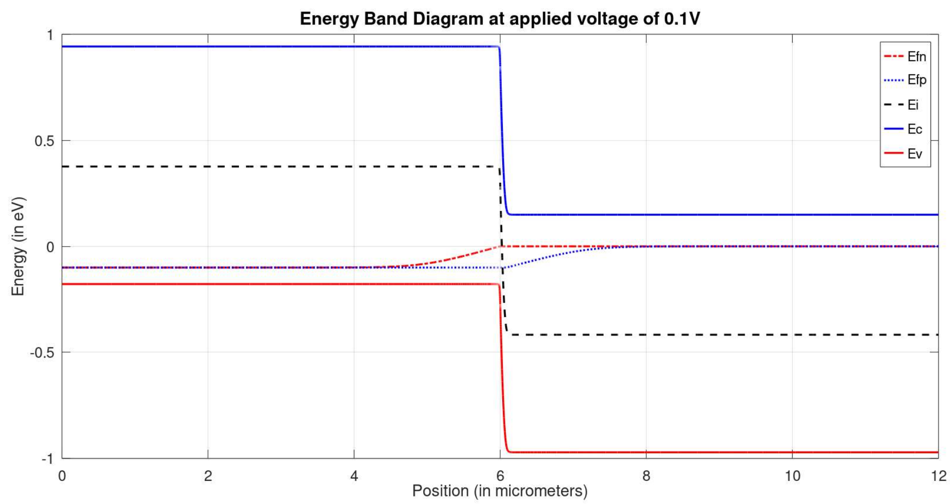


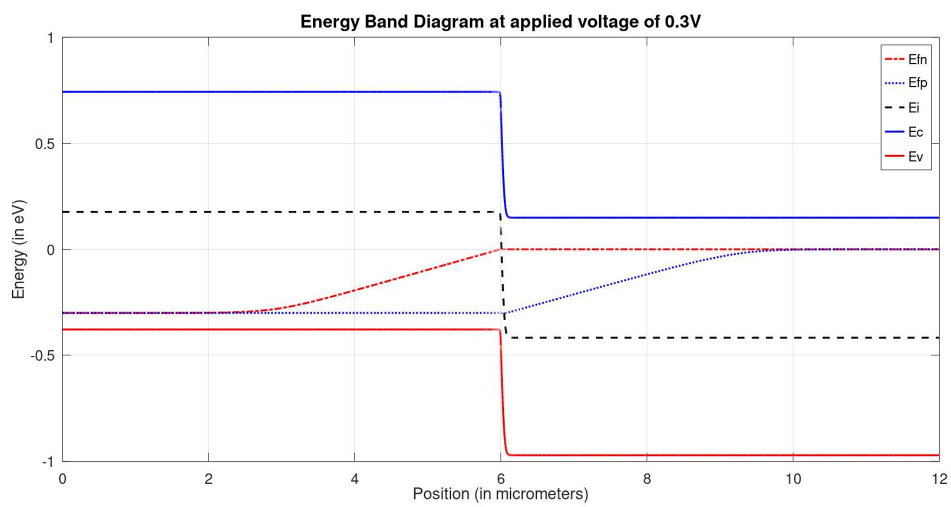




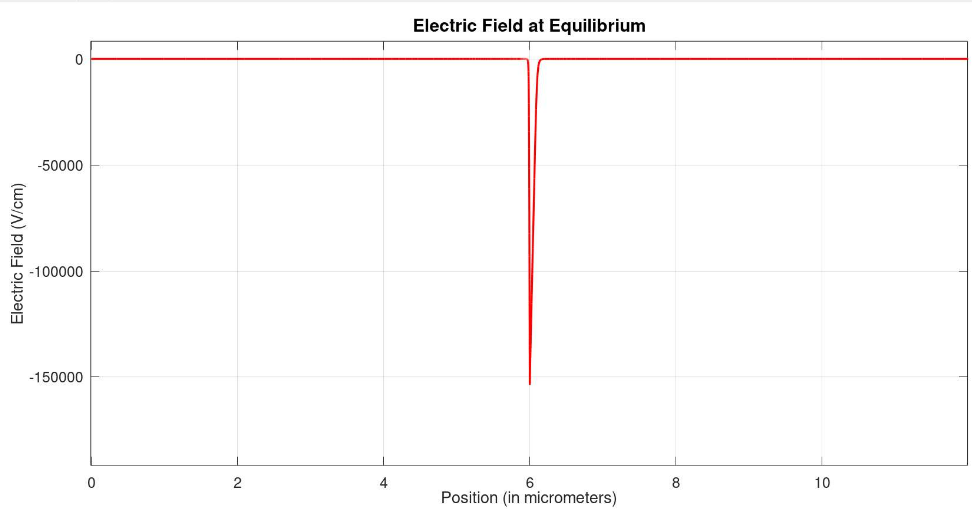
Structure of Energy Band

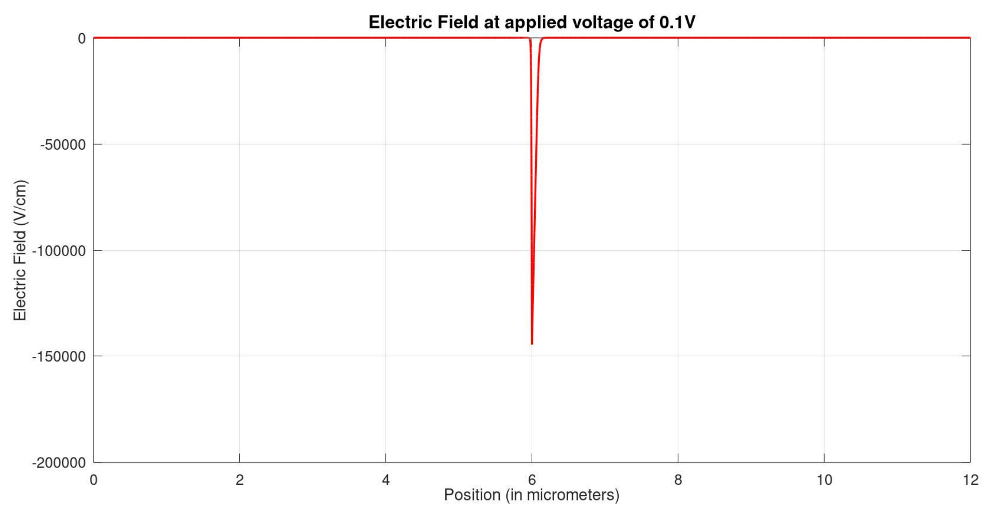


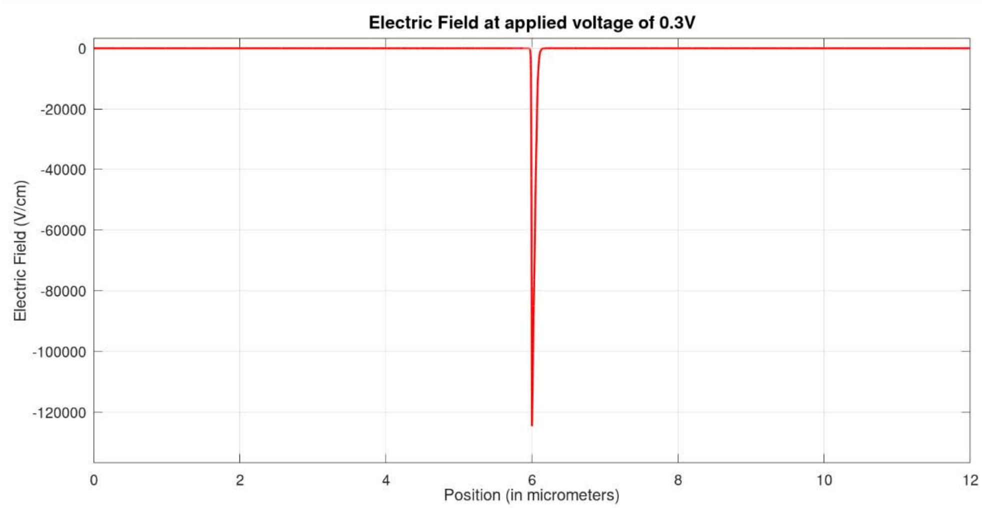




Electric Field







Current-Voltage Characteristic